USLOSS User's Manual

1.0 General Description

USLOSS (Unix Software Library for Operating System Simulation) is a library that simulates a simple computer systems. USLOSS allows students to experiment with low-level systems programming concepts such as interrupt handling, device drivers, and process scheduling. USLOSS is written in the C programming language to allow fast execution and easy debugging of student programs.

USLOSS implements a single-core CPU with user and kernel modes, a high-level context-switch facility to allow easy switching between processes, interrupts, a memory-management unit (MMU) that allows for virtual addressing and virtual memory, and the following devices: a periodic clock interrupt, a count-down timer device, a system call (syscall) facility, four user terminals, and two disk storage devices.

2. Using USLOSS

2.1 Building from source on your personal Linux or Mac:

Create a directory in your account for USLOSS. In what follows, **`<yourDirectory>`** refers to the directory you just created. **`cd`** to **`<yourDirectory>`**
Copy the USLOSS tarball to your directory. The tarball can be found on lectura at:

```
      /home/cs452/fall15/usloss/usloss-2.9.tgz
```

Untar the USLOSS tarball:

```
   tar xvzf usloss-2.9.tgz  .
```

Change directory to **`usloss/src`**.

If compiling on Linux, edit **`Makefile`**. Find the line:

```
   CFLAGS += -D_XOPEN_SOURCE
```

Comment this line (put a # at the start).

If compiling on OS X, no changes are needed in **`Makefile`**.

Type **`make install`**.

This will compile and install the library **`libusloss<version>.a`** in **`./build/lib`**, and the header file **`usloss.h`** in **`./build/include`**. The **`<version>`** in the library name is the USLOSS version number, e.g. **`libusloss2.9.a`**.

If you have not already done so, create a directory that you will use for working on phase1 of the project. In this phase1 directory, create a link to USLOSS:

```
   ln -s <yourDirectory>/build usloss
```

This will create a soft link named **`usloss`** in your phase1 directory that points to the build directory (the directory that contains **`lib/`** and **`include/`**).

The next step is to write a C program that uses USLOSS (referred to as the operating system, or OS). Essentially, this means you start working on phase1 at this point. See the provided starter files for phase1.

The short version: All source files must include the file **`usloss.h`**. USLOSS defines **`main`** and will invoke the routine **`startup`** after USLOSS is initialized. The OS must therefore define **`startup`**. Similarly, the OS must provide a **`finish`** routine that is invoked by USLOSS when it shuts down (this is used primarily for debugging and is discussed later).

Once the C program has been written, you should create a **`Makefile`** to handle compilation. When compiling a source file, use a command of the form:

```
   gcc $(CFLAGS) -c -I<usloss>/build/include osfile.c
```

The **`-I`** option will allow the compiler to find **`usloss.h`** (**`<usloss>`** is the pathname of the USLOSS source directory). To create the executable file, use a command of the form:

```
   gcc $(CFLAGS) -o os -L<usloss_>/build/lib osfile.o -lusloss2.9
```

This will create an executable called **`os`**, augmented by the routines in **`osfile.c`**.

The resulting executable is run just like any other compiled C program If it is compiled with the **`-g`** option, then a standard C debugger such as **`gdb`** can be used for debugging (see Section 6).

2.2 Using USLOSS pre-installed on Lectura

This section is under construction...

3. Processor Features

USLOSS simulates a simple single-core CPU, providing kernel/user modes, interrupts, and simple context-switch support.

3.1 Modes of Operation

The simulator has two modes of operation: *kernel* and *user*. Kernel mode is *privileged*, in which all USLOSS operations can be invoked. User mode cannot access hardware devices nor invoke certain USLOSS operations; doing so will cause an illegal instruction exception, which in turn will cause USLOSS to dump core. For a complete list of which operations are disallowed while in user mode, see the command summary at the end of this manual. USLOSS starts up in kernel mode; to switch to user mode the OS must change the mode bit in the processor status register (see Section 3.4).

3.2 Interrupts

The interface to the USLOSS interrupt system consists of an interrupt vector table and two function calls. When an interrupt occurs, USLOSS switches to kernel mode, disables interrupts, and calls the appropriate routine as indicated by the interrupt vector. Six different types of interrupts/devices are simulated (symbolic constants are shown in parentheses):

- clock (**`USLOSS_CLOCK_INT`** and **`USLOSS_CLOCK_DEV`**)
- countdown time (**`USLOSS_ALARM_INT`** and **`USLOSS_ALARM_INT`**)
- terminal (**`USLOSS_TERM_INT`** and **`USLOSS_TERM_DEV`**)
- system call (**`USLOSS_SYSCALL_INT`**)
- disk (**`USLOSS_DISK_INT`** and **`USLOSS_DISK_DEV`**)
- memory-management unit (**`USLOSS_MMU_INT`**)

See Section 4 for a detailed description of the device interrupts, Section 3.3 for a description of system calls, and Section 5 for a description of the MMU.

To handle the various interrupts, the OS must fill in the interrupt vector with the addresses of the interrupt handlers. This table is declared as a global array USLOSS (**`USLOSS_IntVec`**), and is simply referenced by name. The symbolic constants for the devices are designed to be used as indices when initializing the table. For example, to install an interrupt handler for the clock interrupt, the following statement could be used:

```
USLOSS_IntVec[USLOSS_CLOCK_INT] = clock_handler;
```

Thereafter, **`clock_handler`** will be invoked whenever a clock interrupt occurs. If an interrupt occurs and the interrupt vector for that type of interrupt has not been initialized, it will generally cause the simulator to print an error message and dump core. *Always initialize the interrupt vector before enabling interrupts*. Interrupts are disabled when **`startup`** is invoked, providing an opportunity to initialize the interrupt vector. The interrupts can subsequently be enabled by setting the *current interrupt enable* bit in the processor status register (see Section 3.4).

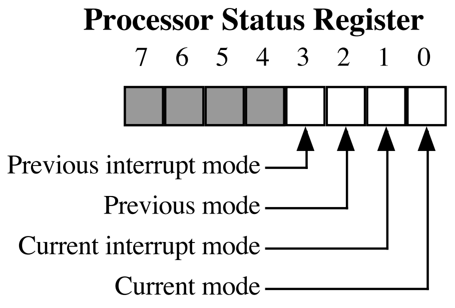
Interrupt handlers are passed two parameters. The first parameter indicates the type of interrupt, allowing the same handler to handle more than one type of interrupt, if desired. The second parameter varies depending on the type of interrupt. Generally, an interrupt handler takes some action and then returns, allowing execution to resume at the point where it was interrupted. In some cases, however, the interrupt handler may execute a context switch, in which case the current machine state is saved and execution is resumed at another point. An interrupt handler that invokes a context switch must be carefully written, as the state of the OS after the switch will almost certainly be different than the state before.

3.3 Syscall

The simulator treats system calls as a form of interrupt, routing them through the interrupt vector. The function pointed to by **`USLOSS_IntVec[USLOSS_SYSCALL_INT]`** is invoked each time **`USLOSS_Syscall`** is called. The handler resembles an interrupt handler: USLOSS switches to kernel mode, disables interrupts, and invokes the system call handler with two parameters. The first parameter contains the interrupt number (**`USLOSS_SYSCALL_INT`**), which will probably be of little interest. The second parameter is the argument passed to **`USLOSS_Syscall`**. This is typically a pointer to a structure or array containing such information as a syscall number and any other arguments the syscall requires.

Returning from a **`USLOSS_Syscall`** is similar to returning from any other interrupt handler: the calling process may be resumed via a normal function return, or a context switch may be performed.

3.4 Processor Status Register (PSR)



The state of the USLOSS processor is stored in the Processor Status Register (PSR). The bits in the PSR indicate the kernel mode and the state of the interrupts.

The *current mode* bit is **`1`** if the processor is in kernel mode, **`0`** otherwise. The *current interrupt enable* bit is **`1`** if interrupts are enabled, **`0`** otherwise. When an interrupt occurs, the processor saves the current mode and interrupt enable bits into the "previous" bits. When the interrupt handler returns, the current bits are restored from the previous bits. Thus, an interrupt handler can determine which mode the processor was in prior to the interrupt by looking at the *previous mode* bit. Changing either of the "previous" bits in the interrupt handler will change the value of the "current" bits when the interrupt handler returns. Changing the "current" bits causes the mode and/or interrupt enable to change immediately. The PSR is accessed via **`USLOSS_PsrGet`** and **`USLOSS_PsrSet`**. Macros are defined in *usloss.h* for the OS to use in accessing the PSR bits.

3.5 Process Support

USLOSS provides a context switch mechanism for switching between processes. The context of each process is stored in a structure of type **`USLOSS_Context`** (include *usloss.h* for the definition). The internals of a **`USLOSS_Context`** structure should not be directly modified by the OS; only **`USLOSS_ContextInit`** and **`USLOSS_ContextSwitch`** may do so. Also, each process must have its own stack and own context. The OS can share code between processes, but not stacks or contexts.

Prior to creating a new process, the OS must first allocate an unused **`USLOSS_Context`**. The OS can allocate the structure statically (as part of a global variable or array) or dynamically (using malloc). Typically, the OS will embed the **`USLOSS_Context`** as a field in a process control block (PCB).

3.5.1 Initializing a Context

```
USLOSS_ContextInit(USLOSS_Context *context, unsigned int psr,
                   void *stack, in stackSize, void(*func))
```

The **`context`** parameter is the context structure to be initialized. The **`psr`** is the initial PSR for the process (see Section 3.4). The **`func`** is the address of the initial function the process is to execute. The **`stack`** and **`stackSize`** define the stack for the process; the stack can be allocated either statically (global variable) or dynamically (**`malloc`**). The stack size depends upon the complexity of the process (i.e., the depth of the procedure call nesting and size of local variable declarations), but the stack must be at least of size **`USLOSS_MIN_STACK`**, as defined in *usloss.h*. Note that **`USLOSS_ContextInit`** will only initialize the context for the new process; to actually begin executing the process the OS must call **`USLOSS_ContextSwitch`**.

The function specified by **`func`** must never return; otherwise, the stack will underflow. USLOSS will catch this and dump core, but the OS should use a standard wrapper function as the initial function for each process. The wrapper invokes the real initial function for the process and does something more civilized than dump core if the function returns (perhaps it could print a warning message and call **`halt`**). Note that USLOSS is being polite; a real CPU will likely crash if a stack underflows.

There is an important caveat concerning the creation of new contexts via **`USLOSS_ContextInit`**. When the OS calls **`USLOSS_ContextSwitch`** for the first time with a new context, USLOSS will jump directly from inside **`USLOSS_ContextSwitch`** to the starting function of the new process. Any code that follows the call to **`USLOSS_ContextSwitch`** will not be executed in the context of the new process.

3.5.2 Switching Contexts

```
USLOSS_ContextSwitch(USLOSS_Context *old_context,
                     USLOSS_Context *new_context)
```

This function performs a context switch, where **`old_context`** is a pointer to a context structure in which the state of the currently running process is to be stored, and **`new_context`** is a pointer to a context structure containing the state of the new process to be run. The **`USLOSS_Context_switch`** routine will save the currently running process in the old context, including the PSR, and switch to the process stored in the new context. If the OS does not want to save the current context (e.g., it is starting the first process), then pass **`NULL`** as the value of **`old_context`**.

4.0 Devices

USLOSS supports several device types: clock, alarm, terminal, and disk. Devices are read using **`USLOSS_DeviceInput`** and written using **`USLOSS_DeviceOutput`**.

4.1 Clock Device

The clock device invokes the function in **`USLOSS_IntVec[USLOSS_CLOCK_INT]`** at regular intervals the length of which is determined by the resolution of the virtual timer provided by the platform on which USLOSS runs. On *lectura*, this interval is approximately 20 milliseconds, or one fiftieth of a second, and is defined by **`USLOSS_CLOCK_MS`** (defined in *usloss.h*). It should be noted that this clock interrupt is both far more infrequent and irregular than the one that would be provided by a real CPU; nevertheless, it is sufficient to implement multiprogramming and time slicing, as the code should be written to be independent of the frequency of clock interrupts.

Note that the USLOSS function **`USLOSS_Clock`** returns the current time measured in <u>micro</u>seconds, not milliseconds. Thus, a clock interrupt will occur approximately every 20,000 time units as reported by **`USLOSS_Clock`**.

4.2 Alarm Device

The alarm device is a count-down timer intended primarily for debugging purposes. It may be set by the user to send an interrupt a given number of clock ticks in the future. The alarm is set by calling **`USLOSS_DeviceOutput(USLOSS_ALARM_DEV, 0, n)`**, where **`n`** is a number between 1 and 255. The alarm interrupt arrives in between interrupts from the regular clock, so synchronization between the two is unnecessary. Several outstanding alarm interrupts may be scheduled at a time. When an alarm interrupt occurs, the function pointed to by **`USLOSS_IntVec[USLOSS_ALARM_INT]`** is called.

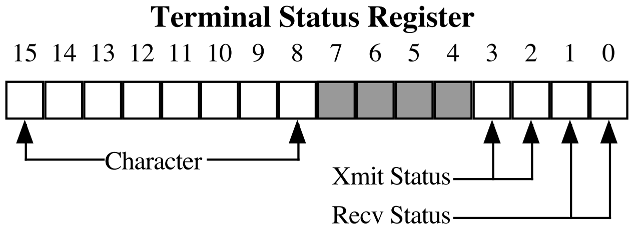
4.3 Terminal Devices

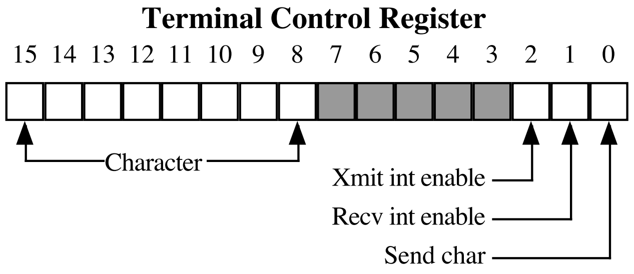
The simulator supports four terminal devices that share a single interrupt (**`USLOSS_TERM_INT`**). Each terminal has a 16-bit status register and a 16-bit control register accessed via **`USLOSS_DeviceInput`** and **`USLOSS_DeviceOutput`**, respectively. An interrupt is generated each time there is a change in the contents of any of the 4 status registers, provided it is not masked by the interrupt mask in the corresponding control register, as described below. When an interrupt is generated, the routine pointed to by **`USLOSS_IntVec[USLOSS_TERM_INT]`** is called. The second parameter passed to the interrupt handler is the unit number of the terminal whose status changed. The terminals are numbered 0-3.

At this point, the terminal's status register should be read immediately by calling

```
   USLOSS_DeviceInput(TERM_DEV, unit, &status)
```

where **`unit`** indicates which terminal's status register to read, and **`status`** is the location in which to return the status. The contents of the status register are shown in the diagram below. Macros are provided in *usloss.h* to extract the fields of the status register. The *xmit status* field indicates the status of the terminal's transmit capability, while the *recv status* field indicates its receive capability. The values for these status fields can be one of **`USLOSS_DEV_READY`**, **`USLOSS_DEV_BUSY`**, or **`USLOSS_DEV_ERROR`**, as defined in *usloss.h*. If the receive status is **`USLOSS_DEV_BUSY`**, then a character has been received on the terminal and is stored in the *character* field of the status register. A status of **`USLOSS_DEV_READY`** means that no character has been received, while a status of **`USLOSS_DEV_ERROR`** indicates a problem. Each terminal has space to store only a single character, so a failure to read the status register immediately upon receipt of a terminal interrupt may result in the loss of the character when another character is received. The interval between character arrival is at least as long as the interval between clock ticks, so there should be plenty of time to respond to a terminal interrupt.





Sending is somewhat more difficult than receiving. To send a character, the OS must first ensure that the terminal is ready to send a character, as indicated by the *xmit status* in its status register. A status of **`USLOSS_DEV_READY`** means it is okay to send a character, whereas a status of **`USLOSS_DEV_BUSY`** means it is not. If you try to send a character while the terminal is busy, the character will be lost. Characters are sent by writing them to the terminal's control register via

`USLOSS_DeviceOutput(USLOSS_TERM_DEV, unit, control)`, where **`unit`** is the unit number of the terminal to be written, and **`control`** is the value to write to the control register. The format of a control register is shown in the diagram. To send a character, put the character value in the *character* field of the control register, and set the *send char* bit of the register. If the *send char* bit is not set, the character will not be sent. Characters can be sent at a maximum rate of one per clock tick.

The remaining two bits of the register consist of an interrupt mask for the terminal. If the *xmit int enable* bit is set, the terminal will generate an interrupt when its transmit status changes; otherwise it will not. Similarly, if *recv int enable* is set, the terminal will generate an interrupt when its receive status changes. Note that it is possible for both interrupts to occur at the same time. If the OS does not want either of these interrupts, then do not set their bits in the control registers.

The OS should set the *recv int enable* bit for all the terminals and leave them on; a receive interrupt will only be generated when a character is received. The OS should only set the *xmit int enable* bit when it has characters to transmit on that terminal; otherwise, it will get a lot of spurious transmit interrupts that are not useful.

There are macros in *usloss.h* to help the OS access the fields in the status and control registers. Note that it is possible for a single interrupt to signify both the reception and transmission of a character on a terminal.

4.3.1 Terminal Files

The four terminal devices read their input from the four files *term[0-3].in*. These files must reside in the directory in which USLOSS is being executed. If a terminal input file is not present, no input will be received from the corresponding terminal. The terminal input files should be created manually using a text editor. Terminal output is written to the files *term[0-3].out*.

A utility called *pterm* is provided to allow users to operate real terminals with the simulator. To connect a real terminal with the simulator, users must log in to that terminal and change to the directory in which the simulation is being run. Users should then enter a **`pterm x`** command, where **`x`** is the terminal number to connect to. If an input file for that terminal exists, the user is given the choice of removing the file or aborting. The terminal is switched into cbreak input mode, and every character typed on the terminal is sent to the simulator and simultaneously written into the corresponding terminal input file (this will provide a record of what input was typed after the simulation terminates). Characters written to the terminal by the simulator are displayed on the screen. To exit, the user may strike either the interrupt or stop (ctrl-Z) keys, which will cause **`pterm`** to reset the terminal to normal mode and exit.

Normally, characters are read from terminal input files or physical terminals at the maximum rate possible, which is one character from each terminal for every four clock ticks. In some cases, it may be desirable to delay input from one or more terminals for a given interval. This may be accomplished by inserting '@' characters in the input files; each '@' character is read by the simulator but does not cause an interrupt and is thus invisible to the OS. Each '@' effectively delays the next input character from that terminal by four clock ticks.ß

4.4 Disk Devices

The disk devices supports the following operations: seeking to a given track, and reading and writing a 512-byte sector within the current track. A disk operation is initiated by a call of the form: **`USLOSS_Device_output(USLOSS_DISK_DEV, unit, request)`**, where **`unit`** is the unit number of the disk to be accessed, and **`request`** is a pointer to a **`USLOSS_DeviceRequest`** structure (defined in *usloss.h*). This structure has three fields: **`opr`**, **`reg1`**, and **`reg2`**.

The **`opr`** field must be one of the predefined constants: **`USLOSS_DISK_READ`**, **`USLOSS_DISK_WRITE`**, **`USLOSS_DISK_SEEK`**, or **`USLOSS_DISK_TRACKS`**. If **`opr`** is **`USLOSS_DISK_READ`** or **`USLOSS_DISK_WRITE`**, then **`reg1`** should contain the index of the sector to be read or written within the current track, and **`reg2`** should contain a pointer to a 512-byte buffer into which data from the disk will be read or from which data will be written. Note that each track on the disk has **`16`** sectors. If **`opr`** is **`USLOSS_DISK_SEEK`**, then **`reg1`** should contain the track number to which the disk's read/write head should be moved. If **`opr`** is **`USLOSS_DISK_TRACKS`** then **`reg1`** should contain a pointer to an integer into which the number of tracks will be stored.

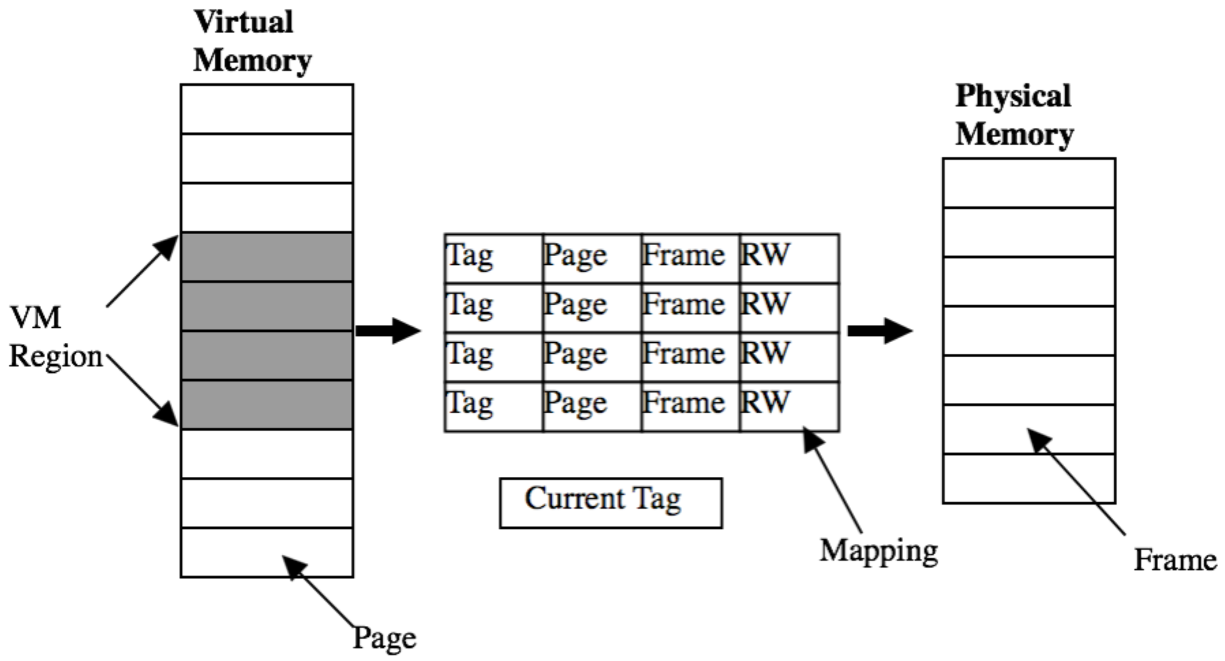
After a request has been sent to the disk, further requests are ignored until the requested operation has been completed, at which point the function pointed to by **`USLOSS_IntVec[USLOSS_DISK_INT]`** is called. The status of a disk device may be obtained by a call to **`USLOSS_DeviceInput(USLOSS_DISK_DEV, unit, &status)`**, which will set **`status`** to **`USLOSS_DEV_READY`** if the device is inactive, **`USLOSS_DEV_BUSY`** if a request is being processed, or **`USLOSS_DEV_ERROR`** if the last request could not be completed.

4.4.1 Disk Files

The disk device stores the contents of each simulated disk in a file called *diskN*, where *N* is the unit number for the disk. USLOSS supports two disks, unit 0 and unit 1. A disk file is updated immediately upon every change to the disk, so no information will be lost when a simulation program terminates abnormally. USLOSS requires that a disk file contain an even number of complete tracks; otherwise, an error occurs upon startup. A utility called *makedisk* is provided to create pseudo-disk files. Note that this utility is needed only to create a new disk; as long as the disk file is not corrupted, the information is preserved between shutdowns and startups of USLOSS.

5. MMU

The USLOSS MMU maps virtual pages to physical page frames, allowing different processes to have different virtual address spaces. Due to the limitations of running USLOSS in a UNIX process, it is not possible for USLOSS processes to have totally separate address spaces; instead the MMU only operates on a single region of the larger shared address space (called the *VM region*). Accesses outside of the VM region are unaffected by the MMU; accesses inside the VM region are mapped by the MMU to allow processes to see different memory contents. The



following diagram illustrates the workings of the MMU.

The MMU contains a set of *mappings*, each containing: *tag*, page number, frame number, and two protection bits (read and write). The MMU uses these mappings to convert addresses in the VM region into physical memory addresses. The MMU performs the following three steps when a process accesses the VM region.

First, the MMU determines which page within the VM region is being accessed.

Second, the MMU finds all mappings whose tag matches the *current tag register*.

Third, the MMU searches the resulting mappings to find one whose page number matches the page that is being accessed.

If a mapping is not found after steps 2 and 3, the MMU will generate an MMU interrupt. This causes the interrupt handler associated with the **`USLOSS_MMU_INT`** interrupt to be invoked, allowing the OS to handle the problem.If a mapping is found, the MMU compares the type of access with the protection bits in the mapping.

If the access is allowed, the frame number from the mapping and the page offset from the virtual address are combined to form a physical address. If the access violates the page's protection a **`USLOSS_MMU_INT`** interrupts occurs.

The size of the VM region, the physical memory, and the number of mappings in the MMU are all specified when the MMU is configured. Varying the relative sizes of the VM region and the physical memory allow the effectiveness of the OS page replacement algorithm to be measured under different workloads and system configurations. Varying the number of mappings in the MMU allows the MMU to function as a single-level page table, or as a translation buffer (TB).

The former is achieved by configuring the MMU so that the number of mappings is equal to the number of pages in the VM region. This allows the MMU to hold mappings for all of a process’s pages that are currently in memory, so that the lack of a mapping for an accessed page indicates a page fault. If, on the other hand, the MMU is configured so that there are fewer mappings than pages in the VM region, the lack of a mapping for a page does not necessarily imply a page fault. The desired page may be in memory, but not mapped by the MMU because there are not enough mappings to go around. In this case the OS removes an existing mapping and adds one for the page that is being accessed.

The tag functionality of the MMU makes it possible for the MMU to store mappings for several processes. The MMU supports **`USLOSS_MMU_NUM_TAGS`** different tags, allowing up to that many different processes to simultaneously have mappings in the MMU. The MMU will not store more than one mapping with a given tag and page, so that the maximum number of mappings that can have the same tag is equal to the number of pages in the VM region. Thus the maximum number of mappings that the MMU can hold is **`USLOSS_MMU_NUM_TAGS`** multiplied by the number of pages in the VM region. It can, however, be configured to hold fewer as described in the previous paragraph. The advantage of using tags is that a context switch between two processes whose mappings are already loaded in the MMU can be achieved simply by changing the value in the current tag register.

Finally, the MMU supports access bits for each physical page frame. A *reference bit* is set when the frame is either read or written, and a *dirty bit* is set when the frame is written. These bits can be also be cleared and set in software, allowing the OS to implement a variety of page replacement algorithms.

5.1 MMU Error Codes

Many of MMU interface routines return the following error codes, defined in *mmu.h*:

Error Code	Meaning
USLOSS_MMU_OK	No error.
USLOSS_MMU_ERR_OFF	MMU has not been initialized.
USLOSS_MMU_ERR_ON	MMU has already been initialized.
USLOSS_MMU_ERR_PAGE	Invalid page number.
USLOSS_MMU_ERR_FRAME	Invalid frame number.
USLOSS_MMU_ERR_PROT	Invalid protection.
USLOSS_MMU_ERR_TAG	Invalid tag.
USLOSS_MMU_ERR_REMAP	Mapping with same tag & page already exists.
USLOSS_MMU_ERR_NOMAP	Mapping not found.
USLOSS_MMU_ERR_ACC	Invalid access bits.
USLOSS_MMU_ERR_MAPS	Too many mappings.

5.2 MMU Routines

`int   USLOSS_MmuInit(int numMaps, int numPages, int numFrames)`

Creates a physical memory containing **`numFrames`** frames, a VM region containing **`numPages`** pages, and initializes the MMU to contain **`numMaps`** mappings. All parameters must be greater than zero, and **`numMaps`** must be less than or equal to **`MMU_NUM_TAG * numPages`**. Initially the MMU has no valid mappings, and the current tag register is **`0`**. Returns a standard MMU error code.

`int   USLOSS_MmuDone(void)`

Releases all the resources associated with the MMU. Subsequent accesses to the VM region will result in a segmentation violation. Returns a standard MMU error code.

`int   USLOSS_MmuPageSize(void)`

Returns the size of a page, in bytes.

`void *USLOSS_MmuRegion(int *numPagesPtr)`

Returns the address of the VM region, and stores the number of pages it contains in **`*numPagesPtr`**. If the MMU has not been initialized, this routine will return **`NULL`**.

`int   USLOSS_MmuMap(int tag, int page, int frame, int protection)`

Stores a mapping in the MMU. **`USLOSS_MMU_ERR_REMAP`** is returned if a mapping with the same **`tag`** and **`page`** already exists. Valid protection values are

`USLOSS_MMU_PROT_NONE` (no access), **`USLOSS_MMU_PROT_READ`**, (page is read-only), and **`USLOSS_MMU_PROT_RW`** (page can be both read and written). Returns a standard MMU error code.

`int USLOSS_MmuUnmap(int tag, int page)`

Removes the mapping with the matching **`tag`** and **`page`**. Subsequent accesses to the page when the current tag is set to **`tag`** will result in an MMU interrupt. Returns a standard MMU error code.

`int USLOSS_MmuGetMap(int tag, int page, int *framePtr, int *protPtr)`

Provides mapping information. If no mapping matches the given tag and page **`USLOSS_MMU_ERR_NOMAP`** is returned, otherwise the mapping's frame is stored in **`*framePtr`**, and the protection in **`*protPtr`**. Returns a standard MMU error code.

`int USLOSS_MmuGetCause(void)`

Returns the cause of the most recent MMU interrupt. **`USLOSS_MMU_FAULT`** means that no mapping matched the current tag and page being accessed. **`USLOSS_MMU_ACCESS`** means that a mapping was found, but that the protections on the page prohibit the attempted access. **`USLOSS_MMU_NONE`** means that an MMU interrupt has not yet occurred.

`int USLOSS_MmuGetAccess(int frame, int *accessPtr)`

Stores the access bits for a frame in **`*accessPtr`**. If **`USLOSS_MMU_REF`** is set the page has been referenced. If **`USLOSS_MMU_DIRTY`** is set the page has been written. Returns a standard MMU error code.

`int USLOSS_MmuSetAccess(int frame, int access)`

Sets the access bits of **`frame`** to **`access`**. Returns a standard MMU error code.

`int USLOSS_MmuSetTag(int tag)`

Sets the current **`tag`** register to tag. Returns a standard MMU error code.

`int USLOSS_MmuGetTag(int *tagPtr)`

Stores the current tag register in **`*tagPtr`**. Returns a standard MMU error code.

5.3 MMU Interrupts

The function pointed to by **`USLOSS_IntVec[USLOSS_MMU_INT]`** will be invoked when an MMU interrupt occurs. The MMU interrupt handler has the following definition:

`void Handler(int type, int offset)`

`type` is the type of interrupt (**`USLOSS_MMU_INT`**). **`offset`** is an integer (cast as a **`void *`**) containing the byte offset from the start of the VM region of the address that caused the interrupt.

USLOSS will take care of restarting the offending instruction when the MMU interrupt handler returns. This means that the address that caused the problem will be given to the MMU again for mapping. If there is still a problem, another MMU interrupt will be generated. The assumption is that the OS will either configure the MMU so that the address will no longer cause an interrupt, or kill the process.

6.0 Debugging Support

USLOSS provides two printing functions to help with debugging. The **`USLOSS_Console`** operation takes printf-style parameters and prints to stdout, and the **`USLOSS_Trace`** operation prints to stderr. You should avoid using **`printf`** and **`fprintf`** as they may cause problems if interrupted.

USLOSS provides a halt operation, **`USLOSS_Halt`**. When invoked, it will cause execution of the **`finish`** routine (defined by the OS), and then terminates execution. A core file is produced if the parameter to **`USLOSS_Halt`** is non-zero. The OS developer might find it useful to have print statements or error checking code in **`finish`** to help in debugging. Lastly, the alarm device may also be used for debugging purposes. It can be set to interrupt at a time that is of interest so that the program status can be examined.

USLOSS can also be debugged using a standard debugger such as **`gdb`**. However, be aware that the use of **`gdb`** is complicated by USLOSS interrupts which are implemented using the **`SIGUSR1`** signal. By default, **`gdb`** catches the **`SIGUSR1`** signal and forces the debugged program to stop. To get around this problem, add the following in your *.gdbinit* file (either in the current directory or in your home directory):

```
handle SIGUSER1 nostop noprint
```

Similarly, when the OS uses the MMU, you should add the following to your *.gdbinit*:

```
handle SIGSEGV nostop noprint
handle SIGBUS nostop noprint
```

The MMU uses **`SIGSEGV`** and **`SIGBUS`** to implement memory mapping. Note that telling **`gdb`** to ignore **`SIGSEGV`** and **`SIGBUS`** will cause it to ignore segmentation violations and bus errors caused by real bugs in the OS, so do not ignore these signals unless the OS uses the MMU.

7.0 USLOSS Quick Reference

The following routines are provided by the simulator. Those marked as **`kernel mode`** are only accessible when in kernel mode (cannot be accessed when in user mode).

```
void USLOSS_Console(char *format, ...);
```

Printf-style write to the console device (stdout).

```
void USLOSS_ContextInit(USLOSS_Context *new, unsigned int psr,
                        void *stack, int stackSize,
                        void (*func)(void));             // kernel mode
```

Initializes the context **`new`** using **`psr`** as the context's initial PSR, the memory pointed to by **`stack`** as the stack memory of size **`stackSize`** (in bytes), and the routine **`func`** as the starting address.

```
void USLOSS_ContextSwitch(context *old, context *new);  // kernel mode
```

Saves the current CPU state (including the PSR) in **`old`**, and loads state **`new`** into the CPU. The **`old`** parameter may be **`NULL`**.

```
int USLOSS_DeviceInput(int dev, int unit, int *status); // kernel mode
```

Sets **`status`** to the contents of the device status register indicated by **`dev`** and **`unit`**. If **`dev`** and **`unit`** are both valid, **`USLOSS_DEV_OK`** is returned; otherwise, **`USLOSS_DEV_INVALID`** is returned.

`int USLOSS_DeviceOutput(int dev, int unit, void *arg);  // kernel mode`

Sends **`arg`** to the device indicated by **`dev`** and **`unit`**. Depending on the device, **`arg`** may be either an integer or a pointer to a structure of type **`USLOSS_DeviceRequest`** containing the device request. If either **`dev`** or **`unit`** is invalid, **`USLOSS_DEV_INVALID`** will be returned; otherwise, **`USLOSS_DEV_OK`** is returned.

`void USLOSS_Halt(int dumpcore);                         // kernel mode`

Causes execution of the **`finish`** routine and then terminates USLOSS. A core file is produced if **`dumpcore`** is non-zero.

`unsigned int USLOSS_PSRGet(void);`

Returns the current value of the PSR.

`void USLOSS_PSRSet(unsigned int psr);                   // kernel mode`

Sets the PSR to the value in **`psr`**.

`void USLOSS_Syscall(void *arg);`

Causes an interrupt of type **`USLOSS_SYSCALL_INT`** and passes **`arg`** as the second parameter to the interrupt handler.

`int USLOSS_Clock(void);`

Return the time (in microseconds) since USLOSS started running.

`void USLOSS_trace(char *format, ...);`

Printf-style write to **`stderr`**.

`void USLOSS_WaitInt(void);                              // kernel mode`

Suspends execution until an interrupt occurs.